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Improving emergency management by modeling ant colonies

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THESIS

IMPROVING EMERGENCY MANAGEMENT BY MODELING ANT COLONIES

by

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March 2015

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The focus of this thesis is to identify whether emergency management can be modeled after ant colonies, perfectly emergent organizations, in order to better manage an autonomous response. An ant colony uses a dense and resilient communications system that incorporates a positive feedback loop, which allows the organization to be adaptable. Currently, emergency management organizations are experimenting with social media to establish a communications system similar to the positive feedback loop used by ant colonies. This thesis advocates that following a disaster, an emergency management organization gather information from the public through an Internet survey. The survey would be quickly processed and provide critically needed information.

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IMPROVING EMERGENCY MANAGEMENT BY MODELING ANT COLONIES

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Submitted in partial fulfillment of the
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ABSTRACT

The focus of this thesis is to identify whether emergency management can be modeled after ant colonies, perfectly emergent organizations, in order to better manage an autonomous response. An ant colony uses a dense and resilient communications system that incorporates a positive feedback loop, which allows the organization to be adaptable. Currently, emergency management organizations are experimenting with social media to establish a communications system similar to the positive feedback loop used by ant colonies. This thesis advocates that following a disaster, an emergency management organization gather information from the public through an Internet survey. The survey would be quickly processed and provide critically needed information.

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TABLE OF CONTENTS

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LIST OF ACRONYMS AND ABBREVIATIONS

AMBER	America's Missing Broadcast Emergency Response
EAS	Emergency Alert System
FEMA	Federal Emergency Management Agency
ICS	Incident Command System
IPAWS	Integrated Public Warning and Alert System
LAFD	Los Angeles Fire Department
UHP	Ushahidi Haiti Project
WEA	Wireless Emergency Alert
WLAN	Wireless Local Area Network

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I. THE INCIDENT COMMAND SYSTEM AND AUTONOMOUS ACTORS

A. PROBLEM STATEMENT

For almost a decade the United States has mandated a standard system for emergency response organization called the Incident Command System (ICS).[1] Some of the benefits of the U.S. version of ICS include: standardized job descriptions and an associated training program; common terms; a structured chain of command with unity of command; authority commensurate with responsibility and task assignments to the person most qualified for the assignment; regulated span of control; and sectoring of work to insure efficiency, effectiveness and safety. In addition, ICS is designed to be scalable in size and complexity, depending on the size and complexity of the disaster or the emergency incident to which ICS is applied.[2]

For many emergencies ICS functions adequately: however, during complex emergencies, the system is often over-taxed. In a complex emergency, the magnitude of the problem exhausts the initial capability of the firefighters, law enforcement, paramedics, and other on-duty professional resources available for an immediate response to the emergency. Complex emergencies create a condition of initial chaos that must be overcome by organizing and adding to the response. A lag time exists while emergency management assesses the situation and organizes a supplementary response from additional resources. The lag period can include the following: the initial assessment, the establishment of communications, the procurement of resources, and assignment of tasks. The time period can be lengthy, depending on the complexity of the emergency. The lag period is also mostly associated with the response phase of a disaster because the lag occurs immediately after the event.

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[1] Jessica Jensen and William L. Waugh Jr, "The United States' Experience with the Incident Command System: What We Think We Know and What We Need to Know More About," *Journal of Contingencies and Crisis Management* 22, no. 1 (2014): 12, DOI:10.1111/1468-5973.12034.

[2] Dick A. Buck, Joseph E. Trainor, and Benigno E. Aguirre, "A Critical Evaluation of the Incident Command System and NIMS," *Journal of Homeland Security and Emergency Management* 3, no. 3 (2006): 1.

A weakness of ICS is that the system fails to accommodate for the autonomous actors who emerge during the lag period between the initial event and prior to the establishment of an organized response. This thesis refers to response autonomy as when an individual acts in accordance with personal decisions and based on local knowledge, rather than acting by the direction of off location management. Professional responders and civilians regularly respond autonomously to disasters without the existence of an established emergency organization. The autonomous response is most notable following the initial event because emergency management needs time to establish an effective organization and provide additional resources. However, even after the establishment of an emergency organization, a degree of autonomous response continues throughout the entirety of the response phase.[3] Is it possible to better enable emergency management to work with autonomous actors?

This thesis aims to identify a means for emergency management organizations to more effectively manage and empower autonomous actors. This thesis argues that autonomous actors are beneficial to the overall disaster response. However, while arguing that autonomous actors are beneficial, this thesis does not approach the topics of response autonomy and emergency management as systems that are mutually exclusive or adversarial. This thesis argues that the integration of specific emergent organizational characteristics into the current ICS structure will allow emergency management to manage autonomous actors without changing the current ICS structure or way of operating. This thesis asks the question: How can emergency management organizations better manage and facilitate autonomous actors?

B. LITERATURE REVIEW

1. Organization Development

There are many different ways in which organizations can be categorized. An organization can be defined by whether the control over the actors is centrally maintained or given freely to the components of the system. Organizations can also be defined by

[3] Jelle Groenendaal, Ira Helsloot, and Astrid Scholtens, "A Critical Examination of the Assumptions Regarding Centralized Coordination in Large-Scale Emergency Situations," *Homeland Security & Emergency Management* 10, no. 1 (2013):120.

which components of the organization are created first. ICS implements a top-down approach to create a centralized coordination system used for resource allocation and conflict resolution.[4] The top-down approach begins by defining the uppermost level of the organization and later adds subsystems when required to meet organizational needs. ICS is also a centralized coordination system.[5] Centralized coordination models consist of linked networks of individual organizations instead of a hierarchical chain of command. In a centralized coordination system, each organization involved maintains separate leadership roles. The independent leadership roles are encouraged to work in cohesion and formulate a common plan so that the effort of each organization creates a unified response.

Jelle Groenendaal, Ira Helsloot and Astrid Scholtens cite evidence of ICS failing to establish an effective authority.[6] Challenge to the effective authority is identified by variability in the rate which orders issued by ICS leadership are followed.[7] Groenendaal, Helsloot, and Scholtens have found that most decisions are made by the first responders at the local level, such as firefighters and law enforcement, and not by professional emergency management. This is especially true during the initial hours of a crisis.[8] Groenendaal and associates have also found evidence of disobedience as great as entire contributing organizations failing to act in accordance with the direction of ICS leadership. The failure to act is due to the contributing organization's a lack of perceived legitimacy in ICS leadership.[9] Failing to obey orders issued by emergency management is evidence of response autonomy. In situations with a significant degree of response autonomy, a bottom-up approach to creating an organizational system can be more effective than a top-down approach.

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[4] Brian Bennett, "Effective Emergency Management: A Closer Look at the Incident Command System," *Journal of Professional Safety* 1111, (2011): 31.

[5] Ibid.

[6] Groenendaal, Helsloot and Scholtens, "A Critical Examination of the Assumptions Regarding Centralized Coordination," 120.

[7] Ibid., 119–20.

[8] Ibid., 120.

[9] Ibid., 119.

The bottom-up approach for creating an organization is done by developing many small organizations at the local level and then linking the local systems into a united structure. The bottom-up system is more effective because it allows decisions to be made at lower levels, which is useful during situations involving time pressure.[10] Additionally, the system forms a greater level of support for the needs of those on the bottom. A bottom-up system could form during disasters by professional and non-professional responders initially organize into small local groups and later connect into a coordinated and holistic system.

2. Response Autonomy

There are a few explanations as to why response autonomy occurs. Jessica Jensen and William Waugh provide a possible explanation for response autonomy in their paper *The United States' Experience with the Incident Command System: What We Think We Know and What We Need to Know More About*. The paper focuses on how the culture of law enforcement creates a lack of trust in ICS because "the top-down command structure is inconsistent with the autonomy normally granted to police officers on the street."[11]

Instead of culture, Groenendaal, Helsloot, and Scholtens believe that response autonomy is influenced by moral and ethical conditions that divert the attention of first responders from managerial level tasking.[12] The Oklahoma City bombing has generally been viewed as a success for the ICS model; however, there were numerous occurrences of police officers leaving assigned positions in traffic control and crowd management to assist victims in the area.[13]

Response autonomy is also demonstrated by non-professional or civilian responders. Kathleen Tierney explains why non-professionals try to help. She states,

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[10] Tierney, Kathleen, "Disaster Beliefs and Institutional Interest: Recycling Disaster Myths in the Aftermath of 9–11." *Research in Social Problems and Public Policy* 11, (2003): 39. DOI:10 1016/S0196-1152(03)11004-6.

[11] Jensen and Waugh Jr, "The United States' Experience with the Incident Command System," 8.

[12] Groenendaal, Helsloot and Scholtens, "A Critical Examination of the Assumptions Regarding Centralized Coordination," 122.

[13] Ibid., 126.

"Despite fear and the entirely realistic desire to flee, individuals and groups facing severe danger try to make rational decisions, and they maintain their connections with others."[14] She has found numerous studies that indicate civilians, who are in the immediate area of a disaster, regularly place themselves into danger while managing evacuations, performing rescues, and transporting victims to emergency personnel.

Both Groenendaal et al. and Tierney believe in the importance of incorporating autonomous actors into an emergency management strategy.[15] Groenendaal and co-authors believe local level organization occurs regularly during disasters due to autonomous actors. Because local level organization occurs, emergency management should incorporate the autonomous actors into an emergency response organizational planning. They advocate additional research on theories, such as the theory of Naturalistic Decision Making, in order to increase the understanding of what influences a bottom-up response approach during emergencies.[16] Tierney believes that a failure to incorporate autonomous response is a detriment to disaster response. The benefit from incorporating autonomous response is an informal dispersion of rescue efforts. The informal dispersion of rescue efforts is better during events with extreme time pressure such as disasters. An attempt to command or coordinate the actions of initial responders may be detrimental to response efforts.[17]

3. Autonomous Groups within Disaster Response

Three types of autonomous groups, relating specifically to emergency response, have been identified: convergence, emergence, and self-organized. Researchers Fritz and Mathewson define the concept of convergence as a "movement toward the disaster-struck area from the outside—external convergence—and movement toward specific points

[14] Tierney, "Disaster Beliefs and Institutional Interest," 35.

[15] Groenendaal, Helsloot and Scholtens, "A Critical Examination of the Assumptions Regarding Centralized Coordination," 128; Tierney, "Disaster Beliefs and Institutional Interest," 39.

[16] Ibid., 128.

[17] Tierney, "Disaster Beliefs and Institutional Interest," 36, 39.

within a given disaster-related area or zone—internal convergence."[18] They believe that the citizens who converge can be placed into five categories: the returnees, the anxious, the helpers, the curious, and the exploiters. Robert Stallings and E. L. Quarantelli identify the emergent group. In their paper, *Emergent Citizen Groups and Emergency Management,* emergent groups are "private citizens who work together in pursuit of collective goals relevant to actual or potential disasters but whose organization has not yet become institutionalized."[19] Lastly, in *Chaos, Complexity, Self-Organization and Us,* Sandra Bloom describes self-organization. She states that self-organization "is a notion that holds that new levels of form, organization, and complexity often arise out of the interchanges between organisms and their contexts."[20] Although an autonomous response during disasters is predictable, the boundaries of the definitions between convergence, emergence, and self-organization are unclear.

4. Organizing Autonomous Actors

The lack of a singular concept for autonomous actors and bottom-up organizations can create difficulties if trying to incorporate autonomous actors in emergency management. Additionally, the research on self-organizing groups, in regard to disasters, focuses more on the who participates and why aspects of autonomous actors and less on the how aspect of organization. Steven Johnson wrote a book about how bottom-up organizations function and how the organizations apply to different fields of study. In Johnson's book, *Emergence: The Connected Lives of Ants, Brains, Cities, and Software*, he explains the importance of emergence to the development of the popular games SimCity and the Sims, advancements in computer based artificial intelligence, the

[18] C. Fritz and J. H. Mathewson, *Convergence Behavior In Disasters: A Problem In Social Control.* Washington, DC: National Academy of Sciences-National Research Council, 1957. Retrieved from Open Library website: http://openlibrary.org/books/OL7161399M/Convergence_behavior_in_disasters.

[19] R. Stallings and E. L. Quarantelli, "Emergent citizen groups and emergency management," *Public Administration Review* 45, 1985: 95.

[20] S. Bloom, "Chaos, Complexity, Self-organization and Us," *Psychotherapy Review* 2, no. 8 (2000): 3.

development of city neighborhoods over time, and how the growth of cell tissue depends more on the neighboring cell than on the master plan, DNA.[21]

Johnson describes emergence as a means of self-organizing from the bottom-up. In emergent systems, independent actors use local knowledge to make individual decisions. The conglomerate of the decisions produces a global behavior.[22] He identifies properties of emergent systems such as independent actors, local knowledge, interconnected communications, and feedback mechanisms. All of the identified properties combine to make a self-organizing system that becomes more orderly and efficient over time.[23] Throughout the book Johnson returns to examples of ants because the advancements in all of the before mentioned topics resulted from a better understanding of how ants organize.

An ant colony relies entirely on bottom-up organization. The colony reacts intelligently to the world around it, even though the individual ants of the colony have no ability to comprehend a world greater than a few square centimeters. The ant colony achieves group intelligence by using an efficient communications system and fostering complete response autonomy. For the ant, there is no question as to who and why in regard to response autonomy because response autonomy is in each ant's genetic instinct and is a necessity for an effective emergent organization. Identifying the basic structures of how ants organize can potentially help emergency management facilitate autonomous responders.

C. METHODOLOGY

This thesis sets aside the traditional questions pertaining to who participates in response autonomy and why. Instead, the focus is how emergent systems are organized and function. This thesis uses ant colonies as a tool for identifying principles of emergent organizations. The ant colony has no central decision maker and consequently creates a

21 Steven Johnson, *Emergence: The Connected Lives of Ants, Brains, Cities, and Software* (New York, Scribner, 2001), 83–5 and 91–5.

22 Steven Johnson, *Emergence: The Connected Lives of Ants*, 77–82.

23 Ibid., 121.

society as a purely emergent organization as opposed to decision capable organizations. Decision capable organizations are organizations in which the majority of members follow decisions made by one or few members. Humans, mostly, create decision-capable organizations, of which ICS-based emergency management is included.[24] The creation of decision-capable organizations carries with it an implied notion that the decision-capable organization will deliver a better result than what can be achieved through emergence, like ants. This thesis uses ant colonies as a benchmark as to what can be achievable by perfectly emergent organizations. In three steps, this thesis identifies the components of ant colonies and how the components facilitate emergence, it compares and contrasts ant and human organizations, and it identifies ways in which current emergency management systems, ICS, can be modified so that emergency management better facilitates an autonomous response.

Chapter II of this thesis reviews the basic structures and communications system of ant colonies. In the same chapter, the thesis explains why ant colonies are an emergent organization and identify fundamental characteristics of the same. Chapter III compares and contrast ant colonies to human organizations. The chapter makes an argument as to the similar nature of signals and examines the structural adaptability of ant and human organizations. Ant organizations are not structurally adaptable and human organizations are structurally adaptable. Chapter III concludes by explaining how humans use technology to alter organizational structure and identify the advantages and disadvantages created by technology. Chapter IV uses the concepts identified in the first two chapters to make an argument for distributing an assessment survey following a disaster. As the Internet becomes more accessible, the infrastructure creates a dense and resilient system that can be used to conduct a rapid survey. The information gathered could create an accurate map for emergency management about the needs of the communities following a disaster. A more accurate assessment will allow emergency management to better align the goals at the top levels of the organization with the goals of the local responders.

[24] Groenendaal, Helsloot and Scholtens, "A Critical Examination of the Assumptions Regarding Centralized Coordination," 118.

II. AN INTRODUCTION TO ANT ORGANIZATION AND COMMUNICATION

The goal of this chapter is to understand the fundamental principles of ant colony organization and communications system in order to explain why ant colonies are efficient bottom-up, or emergent, organizers. The chapter identifies the basic organization and time cycle of an ant colony. Secondly, it explains the mechanisms of ant communication. Lastly, the chapter describes the characteristics of the ant colony that make the colony an efficient bottom-up organization. The characteristics of the organization include a feedback mechanism built in to the means of communication and the colony's reliance on local information.

A. ANT COLONY

1. Components of a Colony

Ant colonies have four components: the queen, the male, the brood, and the workers. The queen is the ant that lays fertile eggs for a colony. In most species of ants, the queen is a solitary figure. A few exceptional species of ant are founded with sister queens and a few other species can have multiple unrelated queens; however, neither configuration is the norm.[25] The second component of the colony is the male ant. The male ant's only purpose is to procreate with the queen and will die soon after it has participated in the mating ritual. Due to the short lifespan, some species of ant have evolved to the point that the male ant is born without a mouth.[26]

The third component of each colony is the brood. The ants that are currently in a stage of life between the egg and adulthood are referred to collectively as the brood. The brood stages include the egg, the larval, and the pupa.[27] The brood is dependent on the colony for nourishment and warmth until fully developed. The youngest generation of ant

[25] Bert Holldobler and Edward O. Wilson, *The Ants* (Cambridge MA, Harvard University Press, 1990), 164–8.

[26] Steven Johnson, *Emergence: The Connected Lives of Ants*, 81.

[27] Holldobler and Wilson, *The Ants*, 164–8.

is egg and it is the first of the brood stages. The second stage is marked by the egg hatching and a larva will emerge. The final stage of the brood is when the larva sheds its final skin and becomes a pupa. Depending on the species of ant, some larva will spin a cocoon for the pupa stage, but most will turn into a resemblance of an ant that has been frozen in a wax like substance. The pupa is the last stage before the ant becomes a fully functioning worker.[28]

The worker ant is the final component of the ant colony. Worker ants are described separately from male ants because every worker is a female.[29] During the earliest stages of adulthood, the ants will remain inside the nest for protection and will predominantly perform functions such as nursing the brood or maintaining the nest. The more mature workers will begin to travel outside the nest to perform foraging and protection functions. Outside of the nest is a dangerous place and the life expectancy of the worker is only 14 days.[30] Depending on the species of ant, workers can be separated by size in addition to age. Small, medium, and large workers are typically how the ant sizes are categorized. The small sized ants predominantly act in functional roles such as nurses or transport services within the nest. The larger sizes predominantly function in roles such as soldier, seed crushers, or transport services outside of the nest. The medium sized ants have no specialty and are the most versatile in terms of functional roles.[31]

The word predominantly is used because all ages and sizes of ant have been documented as having performed every functional role within a colony.[32] However, an ant is more likely to be perform the functions of the ant's size and age specialty.[33] The universality of the worker also mostly depends on the species of ant. Harvester ants have

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[28] John H. Sudd, *An Introduction to the Behavior of Ants*, (London: Edward Arnold Press. 1967), 88 and Bert Holldobler and Holldobler and Wilson, *The Ants*, 164–8.

[29] Charles D. Michener and Mary H. Michener, "American Social Insects: A Book About Bees, Ants, Wasps, and Termites" (New York: D Van Nostrand, 1951), 129.

[30] Holldobler and Wilson, *The Ants*, 174.

[31] Charles D. Michener and Mary H. Michener, *American Social Insects: A Book About Bees*, 124.

[32] Deborah M. Gordon, "The Development of Organization in an Ant Colony," *American Scientist* 83, no. 1 (1995): 51.

[33] Charles D. Michener and Mary H. Michener, *American Social Insects: A Book About Bees*, 124.

a more heterogeneous worker class than leafcutter ants, because the leafcutter ant colony needs various sized ants to perform the different tasks associated with plant gathering.[34]

2. Colony Life Cycle

The life of an ant colony has three stages: the founding stage, the ergonomic stage, and the reproductive stage. The founding stage is marked by a queen ant successful mating and laying the first generation of eggs. Most queen ants are not successful with establishing a colony. With the exception of a few, highly evolved, ant species, both the queen and male ants are born with wings and each fly during the mating ritual on the nuptial day. During the nuptial day, the queen will mate with several male ants. The single mating will be all that the queen needs to birth every generation of the colony for the remainder of the colony's life.[35]

The nuptials will be the first and last flight for the queen because the queen will land onto the ground and chew off her wings following the ceremony. The removal of her wings allows the queen to reabsorb nutrients before she finds or digs a location to birth the first generation of the new colony. The reabsorption of nutrients is necessary because until the first generation of female workers is capable of foraging, the queen must rely on her own resources.[36]

The ergonomic stage is the growth stage of the colony. The first generation of workers is often composed of miniature versions of the smallest members found in a mature colony.[37] Despite the small size, the initial ants are able to perform all of the tasks necessary for the establishment of the colony. The worker's most important task during the ergonomic stage will be to enlarge the nest, take care of the brood, and forage for food. In most species, the queen has had to do everything by herself until the first generation completes the pupa stage. The additional food that the workers provide will

[34] Holldobler and Wilson, *The Ants*, 609,620.

[35] Steven Johnson, *Emergence: The Connected Lives of Ants*, 82.

[36] Charles D. Michener and Mary H. Michener, *American Social Insects: A Book About Bees*,125.

[37] Holldobler and Wilson, *The Ants*, 157.

supply the increased nutrients that are critical for the development of a full sized generation of ant.[38]

The third stage of colony life is the reproductive stage. It typically takes colonies five years to reach the reproductive stage.[39] A colony will begin to produce virgin queens and male ants once the colony to approaches the maximum supportable population.[40] The colonies of the same species time the production of queen and male ants so that queens and males can mate with each other and avoid incest.[41] In some species, the colony can fluctuate between an ergonomic stage and reproductive stage for the remainder of the colony's lifespan. However, in most species the colony will stabilize in size during the reproductive stage. A typical ant colony can live fifteen to twenty years.[42]

B. HOW ANTS COMMUNICATE

1. Semiochemicals

Ants view the world by sensing through chemicals. Ants use pheromones to manipulate the world around them and the manipulation allows ants to communicate. The communication through pheromones is referred to as semiochemical communication.[43] Ants are highly sensitive to signal chemicals and only a few molecules of the chemical are required to identify trails. The economic efficiency of using chemical signals is unrivaled by other systems and gives the ant a great advantage. Chemists have identified that a gram of a chemical would be all that is required to lead a column of ants around the world.[44] A disadvantage is that the chemical signals take a long time to dissipate. A

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[38] Charles D. Michener and Mary H. Michener, *American Social Insects: A Book About Bees*, 125–6.

[39] Deborah M. Gordon, "The Development of Organization in an Ant Colony," 55.

[40] Holldobler and Wilson, *The Ants*, 159.

[41] Charles D. Michener and Mary H. Michener, *American Social Insects: A Book About Bees*, 125.

[42] Deborah M. Gordon and Alan W. Kulig, "Founding, Foraging, and Fighting: Colony Size and the Spatial Distribution of Harvester Ant Nests," *Ecology* 77, no. 8 (1996): 2394.

[43] Steven Johnson, *Emergence: The Connected Lives of Ants*, 75.

[44] Edward O. Wilson, "Ants," *Bulletin of the American Academy of Arts and Sciences* 45, no. 3 (1991): 21.

signal may continue to influence the behavior of encountering ants long after the message has lost relevance.[45]

Ants detect the chemical signals with glands predominately located on the head and on the gaster. The gaster is the third section of the body or the section that would be casually referred to as the rear.[46] Wilson describes the sensory ability of the ant in the following quote, "the body of each worker contains between ten and twenty exocrine glands that release chemical secretions to the outside of the body in one manner or another, to be smelled or tasted by fellow members of the colony."[47] Twelve types of functional signals have been identified by scientists. Alarm, simple attraction, recruitment, group effect, recognition, and territorial/home indicator signals are the signals which effect group behavior. The remaining six signals are used for individual to individual communication, such as indicating grooming needs, and the signals do not function to create a group effect.[48]

2. Pheromone Strength

Ants are highly sensitive to the gradient or strength of chemical signal that is detected.[49] Returning to the example of the harvester ant, when an increasing number of harvester ants return to the nest from a discovered food source, each ant will begin to lay their own pheromone trail so long as there is still food at the source. The strength of the pheromone trail will increase and influence more harvester ants toward the food source. The signal for a food source is a type of recruitment signal. Once the food source is depleted, the ants will no longer leave a recruitment signal and the signal trail will be allowed to slowly dissipate.[50] Although the signal will weaken over time, it will continue to attract ants until the signal has fully dissipated. The ant's sensitivity to the gradient of the chemical effects the likelihood that the ant will respond to the signal.

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[45] Holldobler and Wilson, *The Ants*, 246.

[46] Ibid., 5.

[47] Wilson, "Ants," 17.

[48] Holldobler and Wilson, *The Ants*, 227.

[49] Steven Johnson, *Emergence: The Connected Lives of Ants*, 76.

[50] Holldobler and Wilson, *The Ants*, 227.

3. Synergism and Modulatory Communication

Two other ways that ants increase the chances of response to a signal are synergism and modulatory communication. Synergism is when two chemicals, which individually indicate the same or close to the same signal, are detected at the same time.[51] The detection of both chemicals increases the chances that a detecting ant will respond to the chemical. Modulatory communication also increases the chance of an ant responding to a chemical. Bert Holldobler and Edward O. Wilson describe modulatory signals as signals that, "do not release specific fixed-action patterns . . . , but instead alter the probability of reactions to other stimuli by influencing the motivational state of the receiver."[52] An example of modulatory communication is when a species of fire ant releases a poison into the air as a signal to attract additional ants to a food source too large to be carried individually. In addition to the poison, the ant will rub its legs together in an act called stridulating. Stridulating emits a sound in the same way that a cricket chirps. Even though the stridulating has no behavioral response associated with it, upon hearing the sound ants will slow their foraging speed. The slowing allows the chemical signal to spread and increases the rate in which neighboring ants are be recruited by poison.[53]

4. Ritualization

Ants have developed signals through ritualization. Ritualization is, "an evolutionary process where a phenotypic trait is altered to serve more efficiently as a signal."[54] The process of ritualization is not exclusive to ants and is believed to be the means in which most species have developed forms of communication. Through ritualization species have even learned to communicate with other species.[55] Certain aphids have become dependent on ants. Ant-dependent aphids are less likely to produces

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51 Holldobler and Wilson, *The Ants*, 254.

52 Ibid., 253.

53 Hubert Markl and Bert Holldobler, "Recruitment and Food-Retrieval Behavior in Novomessor," *Behavioral Ecology and Sociobiology* 4, no. 2 (1978): 184.

54 Holldobler and Wilson, *The Ants*, 249.

55 J. M. Cullen, "Reduction of Ambiguity Through Ritualization," *Philosophical Transactions of the Royal Biological Sciences* 251, no. 772 (1966): 364–5.

alarm signals and instead rely on warnings transmitted by the host ants. However, the communication goes two ways. The ants also respond to the aphid alarm in the rare event that the aphid produces a signal. Both the aphid and ant chemicals are unique to each species and the chemical compound cannot be produced by the other.[56] Long periods of time are required to build communication systems from evolutionary ritualization. Communication can be changed, altered, and modified but only at the speed of evolution. As a consequence, any variation in ritualized communication will the communication.[57]

C. ANT ORGANIZATION AND EMERGENCE

1. Ants' Organization

Ants are an emergent society because they lack a command structure for organization.[58] The queen ant is named the queen because she births every member of the colony. She is not named the queen because she orchestrates the colony's actions. The queen is isolated from the majority of the colony and lacks any knowledge of the worker's actions outside of her chamber. The queen's lack of knowledge does not come from a flawed communication system. Ant organization relies on the members using local knowledge only.[59] The queen ant has no need to care about the activities of the colony. She instinctively depends on the workers for her survival and the workers instinctively depend on the queen for the survival of the colony.

Ants have minimal intelligence as individuals. The ant's small brain and the short life span suggests that the ant did not evolve with a need of being able to learn.[60] Studies have shown that ants are trainable, but the pace of learning is slow. Scientist have found in a six point maze study conducted on ants and rats that it takes an average of thirty runs

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[56] L. R. Nault, M. E. Montgomery and W. S. Bower, "Ant-Aphid Association: Role of Aphid Alarm Pheromone," *Science* 192, no. 4246 (1976): 1349–50.

[57] Cullen, "Reduction of Ambiguity Through Ritualization," 368–9.

[58] Deborah M. Gordon, "The Development of Organization in an Ant Colony," 50.

[59] Ibid., 52.

[60] Holldobler and Wilson, *The Ants*, 252.

for an ant to learn the maze. To learn the same maze it only takes rats fourteen runs.[61] In a separate study, scientists have shown that ants are trainable as a colony.

Scientists were able to shift colony foraging hours away from the specie's normal foraging hours by providing food at increasingly later or earlier times. The study suggests that colonies gain intelligence by working together. In contrast to maze studies, colony habituation studies are less controlled. The lack of control creates difficulty when trying to quantifying the trainability of ant colonies.[62] The shift in foraging hours is difficult to quantify but easy to explain. Although most ants return to the nest at the normal time, a few ants continue to forage for food. When the late forager is successful at finding food it returns to the nest and recruits ants that have already retired for the day. As the ants become increasingly successful during different times of day more of the ants shift their foraging schedule to accommodate. If all ants are on a strict schedule the colony would not react to the shift in successful foraging times.[63] Ant colonies benefit from the independent actions of the members. When a minority of the members act different from the norm and are able to provide feedback as acting different is successful, the organization become adaptable to the environment.

2. Principles of Emergent Systems

Steven Johnson has identified five principles for bottom-up organization. The principles create macro-intelligence and adaptability in an organization.[64] Macro-behavior means that the group acts in a manner that demonstrates a specific behavior. When emergent organizations are developed properly, the organization demonstrates the behavior of intelligence or macro-intelligence. A micro-motive occurs when a member's actions are motivated by local information.[65] When ant colonies shift foraging times the colonies are demonstrating macro-intelligence through micro-motives. The entire colony shifts the foraging time, macro-intelligence, even though the individual ants are only

61 Sudd, *An Introduction to the Behavior of Ants*, 168–9.

62 Ibid., 167–8.

63 Ibid.

64 Steven Johnson, *Emergence: The Connected Lives of Ants*, 76.

65 Ibid., 77–9.

reacting to the knowledge that is available locally, micro-motives. None of the ants are aware that the there is a shift in normal foraging times.

The five principles for emergent organizations that Johnson advocates are: more is different, ignorance is useful, encourage random encounters, look for patterns in the signs, and pay attention to your neighbors.[66] The first principle is that more is different. More is different is an acknowledgement of the dependency that emergent systems have with large numbers. A few ants will be unable to create macro-intelligence because the micro-motives of each ant will not result in a macro-behavior. Emergent systems require a large number of independent operators so that a macro-behavior is created out of individual actions.[67] The second principle is that ignorance is useful. Ignorance is useful because, "emergent systems grow unwieldy if their component parts become excessively complicated."[68] Emergent organizations perform better when the group is built upon dense and interconnected systems that have a simple design. The simple design prevent complicated micro-motives from influencing upwards into the system as a whole. The ignorance is important for retaining the division between micro-motives and macro-behavior. The simplicity of the language and individual lack of knowledge maintains the barrier between micro-motives and macro-intelligence for ants.[69] While referring to ants, Johnson describes the first two principles combined as, "think locally and act locally, but their collective action produces global behavior."[70]

The third, fourth, and fifth principle are used in combination to create local knowledge. In an emergent system local knowledge is the only knowledge a member needs to act. The principles are to encourage random encounters, look for patterns in the signs, and pay attention to your neighbors. Individuals in an emergent system gain local knowledge from surveying the local environment and interacting with other individuals.[71]

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[66] Steven Johnson, *Emergence: The Connected Lives of Ants*, 77–9.

[67] Ibid., 78.

[68] Ibid.

[69] Ibid.

[70] Ibid., 74.

[71] Ibid., 78–9.

The local information is increased if the number of encounters increases. Johnson describes the effect of the last three principles as, “when individual agents in the system pay attention to their immediate neighbors rather than wait for orders from above.”[72]

Johnson believes harvester ants are a good example of how an emergent organization uses his five principles.[73] Harvester ants are a species of ant that eats seeds. The harvesters are the most predominant ant in regions of dry grasslands and deserts because of the ant’s desire to gather and store seed. The stores give the harvester ant an advantage in environments where food is not always plentiful.[74] The instincts of harvester ants are to spread out from the nest in order to search for and gather seed. The ants gain environmental intelligence based on the success of the foraging. If a foraging harvester ant only finds individual seed, the seed will be brought back to the nest by a forager. When the forager finds multiple seeds, the forager will leave a signal trail to identify the location of the seeds as the ant returns to the nest. Upon arrival to the nest the forager recruits other ants to follow the signal trail back to the grouping of seeds.[75]

Harvester ants also gather intelligence from encounters with fellow ants. As a foraging ant searches for seed, the ant tallies the frequency of interaction between itself and other ants. Additionally, the harvester ant evaluates the role in which the other ants are performing.[76] If a foraging ant encounters many ants, it may move further away from the nest in order to spread out or it may return to the nest so that it can perform a different function for the colony. If the foraging ant encounters no other foraging ants, the ant will move closer to the nest.[77] However, foraging is only one of many functions that the colony needs to survive. Other functions include nursing the brood, cleaning the nest, defending the nest, rebuilding or expanding the nest, etc. The harvester ant will change

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[72] Steven Johnson, *Emergence: The Connected Lives of Ants*, 74.

[73] Ibid., 76.

[74] Holldobler and Wilson, *The Ants*, 609.

[75] Ibid., 614.

[76] Steven Johnson, *Emergence: The Connected Lives of Ants*, 76.

[77] Ibid., 76.

its' activities based local intelligence, or the patterns found in the environment and information gathered from other ants. The function of the ant is the micro-motive.

The harvester ant's communication system, semiochemicals, alters the environment and creates a positive feedback mechanism.[78] Ants not only follow signals, but the ant will contribute to the signal if the ant is in agreement. More ants will participate in the function as the signal becomes stronger. The culmination of ant functions will have an associated macro-behavior that changes with the environment. The communications system allows the harvester ant colony to be able to shift the macro-behavior for a seasonal droppings of seed or for a threat to the nest. The macro-behavior results from the constantly shifting micro-motives.

The macro-behavior is also able to overcome errors in micro-motives. Harvester ants are individually prone to failure. Harvester ants have been documented to fail by carrying undesirable goods, such as bird poop, back to the nest. In the event poop makes it back to the nest, the poop is rejected near the entrance of the nest so the colony is not infected by the undesirable good.[79] Another indication of failure is a ring a plants growing around the entrance to the nest of harvester ants. Each plant represents a viable seed that was inappropriately rejected at the nest's entrance or retrieved and discarded from the colony's stores.[80] A harvester ant's micro-motives are known to exhibit flaws, but the macro-behavior of the colony is such that the colony intelligently manages the needs.

D. CHAPTER II CONCLUSION

This chapter explored the components of the ant colony and life cycle. Additionally, the chapter identified the communications system that ants use to affect colony behavior. The chapter used the basics of ant organization to make a case for why ant colonies effectively implement emergent, or bottom-up, organization. Effective bottom-up organizations allow the members of the organization to make decisions based

[78] Steven Johnson, *Emergence: The Connected Lives of Ants* ,78-9.

[79] Charles D. Michener and Mary H. Michener, *American Social Insects: A Book About Bees*, 157.

[80] Ibid., 157.

on local knowledge. Local knowledge is attained from the environment and from other members who are encountered. The activities of the member are representations of the member's micro-motives. The collective of the organization's micro-motives creates a macro-behavior. The macro-behavior of the system is most effective when the organization has many members acting in accordance with their micro-motives and when there is a barrier in place to maintain local actor ignorance. The local actor ignorance means that the members of the system do not need to know about the macro-behavior for the macro-behavior to be effective. Additionally, the ignorance prevents the macro-behavior from becoming over complicated by complex micro-motives. So long as the system has a positive feedback system, gradual shifts in micro-motives will eventually and appropriately shift the macro-behavior of the system.

III. THE PROPAGATION OF SIGNALS AND RESPONSE TO SIGNALS IN ANT AND HUMAN ORGANIZATIONS

Chapter I explained how the actions of professional and non-professional responders are at least partially represented by an autonomous response, or independent decision making, during the entire portion of an events' response phase. In order to better understand emergence organizations, Chapter II identified how an ant colony functions. The chapter explained how ants have no ability to orchestrate the actions of fellow ants. The signal propagated by ants only affects the likelihood that other ants will partake in the desired activity. Although both ant colonies and human organizations are designed to propagate signals that influence that the entire organization, neither organization achieves full membership compliance.

This chapter will first make an argument as to the similar nature of signals in ant colonies and human organizations due to both organizations consisting of independent decision makers. Secondly, it will examine the structural adaptability of ant and human organizations. Chapter II explained how ant colonies can adapt to an environment by shifting foraging times and by changing the number of ants that are partaking in a function at any given time. However, the structure of the ant organization is not adaptable. This chapter will explain why the organizational structure of the ant colonies is not adaptable whereas human organizations are structurally adaptable. This chapter will lastly explain how humans use technology to alter organizational structures by identifying the structural differences between an ant colony and a human organization. The alterations create advantages for human organizations, such as removing the need for a population density, and disadvantages, such as a loss of information accuracy. The difference between ant colonies and human organizations will be important to understand as Chapter IV explains how and why humans should use technology to alter emergency management. The alteration would make emergency management more structurally similar to an ant colony.

A. THE NATURE OF SIGNALS IN EMERGENT ORGANIZATIONS

The most substantial similarity between ant and human organizations is that both organizations consist of independent actors. Because both organizations use independent actors, this thesis argues that it is best to view the signals propagated in an emergent organization as a means of setting conditions rather than as a means of giving orders. To view the signals as giving orders is flawed because the term applies a connotation that disregards the ability of the receiver to act independently. To view the signals as setting conditions is better because it implies that the information contained in the signals is more about providing information regarding the environment and less about restricting a member's independence. The signals used in emergent organizations only increase the chances that an independent actor will function appropriately for the environment and in a manner that will be beneficial to the organization.

The use of alarm signals are a good comparison between ant and human organization affecting signals. Alarm signals are considered to be signals that encourage the members of a system to, "move away from a potentially dangerous stimulus, either calmly of in panic, or charge toward it aggressively, or simply mill about in a state of heightened alertness."[81] The definition for an alarm signal is used by Edward Wilson in reference to ants and emergent organizations. As discussed in Chapter II, ants use semiochemicals in order to incite specific reactions from other ants, however not all ants alter their functions as a result of receiving the signal.[82] The stronger an alarm signal becomes the more likely an ant will alter its actions, but ants are never required to obey signals.[83] Examples of human alarm signals include a fire, a tornado, or an air raid alarms. Humans also use alarm signals that don't have associated audible transmissions. An example of such a signal would be when a city or state issues an evacuation order or issues weather announcements such as a flash floods warning. Each of these alarm signals are organization-affecting signals because the signal universally applies all

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[81] Holldobler and Wilson, *The Ants*, 260.

[82] Wilson, "Ants," 21.

[83] Ruth Chadab and Carl W. Rettenmeyer, "Mass Recruitment by Army Ants," *Science* 188, no. 4193 (1975): 1124.

members of the organization, but not all members heed the signal. The signals function as a condition-setting signal because they propagate information about the environment with the hope of altering the actions of the members within the organization.

The tornado warning alarm is a specific example of a human, condition-setting signal that is not obeyed by every member of an organization. Bimal Kanti, Paul Mitchel Stimers, and Mitchel Stimers conducted research on the compliance rate of tornado warning alarms during the Joplin, Missouri, tornado on May 22, 2011.[84] The tornado in Joplin was a category F-5 that measured miles wide and consisted of multiple funnels. The researchers found the following variables to have statistical significance: females were more likely to seek shelter; if a person was at home, the person was more likely to take shelter; and if a person had previous tornado experience, that person was less likely to take shelter. The analysis also showed a fourth category, the number of signals received, to have a strong positive correlation, but failed to be statistically significant. The lack of significance for the fourth category is likely due to the small sample size of 141.[85] Additionally, there were 15 participants who failed to take shelter because the participants were unaware of the tornado warning at the time of the storm.[86] In total, seventy seven percent of the aware population took cover during the tornado warning in Joplin.[87] Tornado warning alarms merely notify the people about the condition of the environment. There are many reasons as to why humans might heed signals notifying danger and many reasons as to why humans fail to heed the same signals. However, the results of the survey clearly indicate that the people receiving the tornado alarm make an independent decision as to whether the signal will be adhered to.

B. EVOLUTIONARY RITUALIZATION

The adaptability of organizational structures depends on how the communication system is created. A substantial difference between ant and human organizations is how

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84 Bimal Kanti Paul, Mitchel Stimers, and Marcellus Caldas, “Predictors of Compliance With Tornado Warnings Issued in Joplin, Missouri, in 2011,” *Disasters* 39, no. 1 (2014): 116–8.

85 Paul, Stimers, and Caldas, “Predictors of compliance with tornado warnings,” 116–8.

86 Ibid., 117.

87 Ibid.

the communications system is created for each organization. The ant's communications system is almost completely gene transferred, whereas the human communications system are a mostly a learned process. Although both organizations rely on an established standard of communicating, the means of creating the standard drastically changes the adaptability of each organizational structure. The means of establishing the ant colony's communications system is evolutionary ritualization. As defined in Chapter II, evolutionary ritualization is, "an evolutionary process where a phenotypic trait is altered to serve more efficiently as a signal."[88] The lengthy time it takes to establish a communications system through evolutionary ritualization means that the organization will be unable to structurally change quickly. The means for establishing human communications system is learned ritualization.[89] Because humans learn to communicate through a mostly social process, the organizational structures are adaptable and can change in a relatively short amount of time.[90]

Ant colonies use evolutionary ritualization to establish a communications system. As discussed in Chapter II, the organization and related signals used by ant colonies have come to existence after repetition for millions of years.[91] Ants are not taught how to perform functions or how to adjust functions when responding to signals. The instincts of ants have developed with a precision so that most ants in the colony are born ready to act functionally the same as every other ant in the colony. Although some ants respond incorrectly and demonstrate flawed micro-motives, the flawed ants are a small enough proportion of the colony to not affect the macro-behavior.[92] Because the ant colony relies on a communications system that is transferred by birth, organizational structure cannot change in a short amount of time.

88 Holldobler and Wilson, *The Ants*, 249.

89 Charles J. Lumsden and Edward O. Wilson, "Translation of Epigenetic Rules of Individual Behavior into Ethnographic Patterns," *Proceedings of the National Academy of Sciences of the United States of America* 77, no. 7, (1980): 4382.

90 Holldobler and Wilson, *The Ants*, 249–53.

91 Ibid., 249–53.

92 Sudd, "An Introduction to the Behavior of Ants," 167–9.

Studying ant organizations is useful because the strategies implemented by ant colonies can be used as a benchmark of minimal efficiency that is required for success.[93] Through evolution, the instincts of ants are a time-tested compilation of reactions that have ensured colony survival through the trials and challenges that face ant colonies.[94] The ants' compilation of instinctual reactions are indicative of an organizational strategy that achieves a minimum success rate which ensures colony survival. An example of an ant that is obviously not perfectly efficient, but efficient enough to be successful at surviving is the army ant. The next paragraph will explain how an army ant colony makes a daily transition from resting to hunting and back to resting. The army ant does not have to be the quickest at organizing a hunting column every morning. Rather, the strategy used by army ants has to be quick enough to ensure the survival of the colony.[95] Because the ant's organizational strategy is effective enough to ensure survival, the ant colony should be studied and used as a benchmark for what is achievable in a perfectly emergent organization. As human organizations implement organizational strategies, the organization should ensure that the strategy achieves a better result than what could be achieved by ants.

Army ants are quick enough to transition between night and daytime activities to ensure colony survival. Army ants are a type of ant which hunts during the day time and returns to the bivouac at night for rest and to relocate the colony. The bivouac is what is created when army ants huddle together in a ball instead of building a physical nest.[96] The daily cycle of hunting and relocating makes the efficiency of the organization and transition paramount to the colony's survival. The colony only has from sunrise to sunset to locate, raid, and return the prey to the bivouac.[97] However, traffic jams have been documented to regularly occur during the transition between a colony resting and

93 Holldobler and Wilson, *The Ants*, 249–53.

94 Ibid., 249–53.

95 Chadab and Rettenmeyer, "Mass Recruitment by Army Ants," 1124–5.

96 I. D. Couzin and N. R. Franks, "Self-Organized Lane Formation and Optimized Traffic Flow in Army Ants," *Proceedings: Biological Sciences* 270, no. 1511 (2003): 139.

97 Chadab and Rettenmeyer, "Mass Recruitment by Army Ants," 1124–5.

migrating to a colony raiding.[98] A daily traffic jam is not indicative of organizational efficiency. Also, as the column begins to form for the day, the ants closest to the beginning of the column are hesitant. The hesitation indicates that the column is led from behind.[99] The traffic jams and hesitancy cause questions about the efficiency of a raiding column. The transition between night and daytime activities is not the most efficient process, but it is efficient enough to ensure colony survival.

C. LEARNED RITUALIZATION

Converse to ants, humans use a standardization process of socialized learning in order to implement a communications system.[100] This thesis refers to the socialization process as learned ritualization. An organism relies on pure learned ritualization when the organism has no innate predisposition to favoring a behavior.[101] Although, humans do not rely on pure learned ritualization, humans rely on mostly learned ritualization.[102] This section will briefly describe what learned ritualization is, and why learned ritualization allows humans to quickly change organizational structures.

Humans developed languages, professions, and cultures as components of learned ritualization. Humans use their languages, professions, and cultures to effectively communicate and perform functions by standardizing the meaning of signals. The learning process allow for societies to adapt, invent, and change quickly to the environment around them. Ritualization is important to the ant because it standardizes communication and allows the colony to function. The learned ritualization is important to humans because it also standardizes communication and allows for organizations to function. However, the learned aspect, an aspect that ants lack, allows humans to make changes to society and become more adaptable in a relatively quick manner.

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98 Sudd, *An Introduction to the Behavior of Ants*, 51.

99 Ibid.

100 Lumsden and Wilson, "Translation of Epigenetic Rules of Individual Behavior," 4382.

101 Ibid.

102 Ibid.

Learning a language is the simplest form of human learned ritualization. Humans have evolved with the ability to learn language at a young age. Learning language begins before children have the ability to speak. Susan Goldin-Meadow has found that when a child points to an object, the child is in the first stage of learning a language.[103] The child is associating meaning to the objects in the world around it. Goldin finds that the number of objects that a child points to at 14 months is a better predictor of vocabulary size at 42 months than the number of words that parents introduce to the same child.[104] The result is the same as the ant's evolution based ritualization process.

Knowing a language is not the final or only stage of the ritualization process. Within any given language humans also learn a specialized language. The specialized language can be associated with a profession or a trade. Robert Yinger refers to a language associated with a profession as the language of practice.[105] However, the language of practice extends beyond the verbal and incudes the skills and culture associated with a profession.[106] Yinger describes the language of practice as, "a set of integrated patterns of thought and action. These patterns themselves constitute a kind of syntax and semantics for action. The words and phrases in this language are behavior, activities, and routines."[107]

Language and professions are not the only human advents to come from ritualization. Culture, traditions, and customs also come from learned ritualization. Gwen Nevill, an anthropologist at Southwest Texas University, compares learning culture to be the same as a child learning language.[108] She suggests that humans learn culture at symbiotic events such as church gatherings, school, and from the community, state, or

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103 Susan Goldin-Meadow, "Pointing Sets the Stage for Learning Language-and Creating Language," *Child Development* 78, no. 3 (2007): 741–2.

104 Ibid.

105 Robert J. Yinger, "Learning the Language of Practice," *Curriculum Inquiry*, vol. 17, no. 3 (1987): 295.

106 Ibid., 293–6.

107 Ibid., 295.

108 Gwen Kennedy Neville, "Learning Culture through Ritual: The Family Reunion," *Anthropology & Education Quarterly* 15, no. 2 (1984): 160–1.

nation.[109] Humans are capable of learning many languages, professions, and cultures so that they can integrate with a number of different organizations.

A disadvantage to learned ritualization is the slow process of learning. Unlike ants, humans are not born ready to function. An example of the lengthy process required for learned ritualization includes the response to a fire alarm. Responding to a fire alarm is something that needs to be taught.[110] The importance of fire drills as a means of ritualizing a response during an emergency is an old concept. An article in a 1906 edition of the Journal of Education, an English publication, explained how school fire drills created the conditions for an orderly escape to safety and prevent chaos from concerned parents and scared children.[111] Later, Everett Braun wrote an article, in 1948, about how the San Louis Obispo Junior High had a fire drill that included the fire department and a controlled fire. The fire department set and monitored a controlled fire in the school's woodshop. He testified that the real fire helped to prevent apathy and allowed for people to practice responding under real conditions.[112] Even today, the United States Fire Administration recommends that the best way for civilians to avoid injury and death by fire is to have a preset and practiced plan of escape.[113] Humans do not know at birth how to respond to signals. The process takes time and active practice.

An advantage to learned ritualization is that it allows structural organizations to be adaptable. Through learned ritualization humans are able to change the existing structures and goals of organizations at a relatively quick pace. The evolution of the fire alarm is a simple example of the speed in which humans adapt. Until the invention of the telegraph in 1840, the ringing of church or town bells, in conjunction with roving

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109 Neville, "Learning Culture through Ritual," 161.

110 National Fire Data Center, "Civilian Fire Fatalities in Residential Buildings (2010–2012)," *Topical Fire Report Series* 15, no. 2 (2014): 9, www.usfa.fema.gov/statistics/ and National Fire Data Center, "Civilian Fire Injuries in Residential Buildings (2010–2012)," *Topical Fire Report Series* 15, no. 5 (2014): 9, www.usfa.fema.gov/statistics/.

111 "Fire Drill," *The Journal of Education* 64, no. 11, (1906): 306.

112 Everett C. Braun, "Fire Drill: Include "Fire" and Fire Dept.!," *The Clearing House* 22, no. 8 (1948): 474–5.

113 National Fire Data Center, "Civilian Fire Fatalities in Residential Buildings (2010–2012)," 9. and National Fire Data Center, "Civilian Fire Injuries in Residential Buildings (2010–2012)," 9.

watchmen, had been the system used by cities to detect a fire and warn the citizens.[114] New York City became the first city to install a municipal fire system in 1847. The system consisted of telegraphs from city hall out to the different fire stations and replaced the traditional use of bells.[115] By 1870 automatic fire alarms would be installed in commercial buildings and shortly after, the early 1900s, automatic protection systems, sprinklers, would also be installed in the same buildings.[116] The span between 1840 and the early 1900s is roughly equal to the average human life time. To completely change an ant colony within the time span of one ant's life is impossible. Ants need a minimum of thousands of years to alter genetic predispositions. The time equivalent in terms of generations is even more impressive. Given that the average life span of an ant is 14 days, humans have not existed long enough to experience the number of generations that it takes to alter the meaning of a signal in an ant colony.[117] Learned ritualization allows humans to quickly alter existing organizations and create new organizations. The simple adaptations can easily occur within the time span of a single human generation. Although an adaptation that takes decades to occur may seem like a long time, the adaptation occurs very quickly when compared to the capability of other species.

D. USING TECHNOLOGY TO CREATE STRUCTURAL DIFFERENCES

A fundamental difference between ant and human signal systems is how the organization propagates the signal. Ant colonies increase the strength of the signal by independent actors adding to the signal.[118] As the number of ants adding to the signal increases, the chances that the signal will alter the behavior of neighboring ants also increases. Ants have included a positive feedback loop within the mass communication system because strengthening the signal requires additional ants to independently verify

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114 Wayne P. Moore, "Fire Alarm System Research: Where It's Been and Where It's Going," National Fire Protection Association, http://www.nfpa.org/~/media/Files/proceedings/firealarmsystemresearchwmoorekeynote.pdf.

115 Ibid.

116 Ibid.

117 Holldobler and Wilson, *The Ants*, 174.

118 Chadab and Rettenmeyer, "Mass Recruitment by Army Ants," 1124.

the environmental condition.[119] Because of the positive feedback loop, ant colonies are less likely than humans to be affected by false alarms. If one ant acts with flawed micro-motives, the signal will not be propagated by additional ants.[120] The incorrect signal will not grow in strength so that the flawed signal influences the entire colony. In contrast, humans use technology to amplify a signal that was decided upon by one or few people.

A fire alarm is an example of a common human signal that only requires one person for the signal to be activated. The lack of a feedback loop enables a wrong decision, or a false alarm, to affect every person within the area covered by the alarm. Based on the fact that ants have flawed micro-motives, ants would likely have more false alarms than humans if a colony was given the technology to amplify the chemical signal of an individual ant.[121] The amplification technology would negatively impact the efficiency of the ant colony. To theoretically reverse the circumstances, imagine fire alarms that functioned similar to the alarm signals of an ant colony. In such a system, the alarm would only activate within a close proximity of where the alarm is initially triggered. The signal would gain in strength and grow in distance as additional people verified the presence of a threat. The signal would eventually grow in strength and be propagated throughout the entire building so long as there are enough people in the building to add to the signal.

The amplification is useful because it allows humans to overcome the need for member density within a given area. As discussed in Chapter II, ants are dependent on large numbers in order to gain adequate local area knowledge.[122] Humans would rely on the same need of adequate member density for a building protected by the ant's fire alarm system. The required density is almost always present in an ant nest, but the required density is much less likely to be continuously maintained in a human building. Residential buildings have few people residing in the buildings during the day. Converse to residential buildings, commercial buildings are likely to have few people in the

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119 Steven Johnson, *Emergence: The Connected Lives of Ants,* 121.

120 Ibid., 121.

121 Ibid., 77–82.

122 Ibid., 77.

buildings at night. However, both buildings are likely to have a few people in the buildings at some point in time. The amplification used by human fire alarms is essential for notifying the residents of danger during times that a building is minimally occupied.

E. CONCLUSION

This chapter first made an argument about the nature of signals in emergent organizations. Both, ants and humans, organize by connecting independent actors and the signals used by the same organizations function as setting a condition. Secondly, this chapter compared the structural adaptability of the ant colony to human organizations. The ant colony is structurally rigid due to evolutionary ritualization. The unchanging strategy of the ant colony is useful as a benchmark for effectiveness. Ant colonies should be studied and used as a comparison for human organizations. Different from ants, humans establish a communications system through the social process of learned ritualization. Establishing a communications system through learned ritualization takes time, but it allows an organizational structure to be adaptable. The structural adaptability has allowed humans to alter organizations as technology advances. A prominent use for technology in human organizations is the amplification of signals. Ant colonies require additional ants to verify the environmental condition for a signal to grow in strength which is a positive feedback loop. The positive feedback loop increases the likelihood that the signal is accurate. The amplification technology that humans implement removes the requirement for member density, but decreases the accuracy of the information that is transmitted. The information in this chapter is important to the next chapter because an argument will be made for altering existing emergency management communications so that the system functions more like the ant's positive feedback system. The alteration is meant to restore informational accuracy to emergency management.

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IV. INTEGRATING A POSITIVE FEEDBACK MECHANISM INTO EMERGENCY MANAGEMENT

Chapter III compared and contrasted the organizational structures of ant colonies and human organizations. The chapter concluded by explaining how humans implement amplification tools to propagate signals. One of the disadvantages to using amplification tools is a reduction in informational accuracy. Ants' retain informational accuracy by incorporating a positive feedback loop in the propagation of signals. This concluding chapter will focus on the communications systems that are used during emergencies and disaster response.

This chapter will do three things. First, it will further define signals as one way and two-way communications systems. The definitions include describing the semiochemical system used by ants is a two way signal, which means that the communications system allows information to be transmitted in addition to be received. It will secondly describe the current attempts by emergency management to establish a two-way communications system through the use of social media. However, using social media has drawbacks. The chapter will end by arguing that an assessment survey should be implemented following a disaster. Ants organize effectively as an emergent organization because their communication system is dense and resilient and because their language is simple. As the Internet grows in accessibility, it provides a dense and resilient communications system that is capable of two-way communications. Further, a survey keeps the language between the public and emergency management simple. It will increase communications efficiency and accuracy by providing emergency management a better assessment of conditions following a disaster.

A. ONE WAY VERSUS TWO-WAY COMMUNICATIONS SYSTEMS

Chapter III explained how humans use technology to amplify the signals of one or few people. Examples of amplified signals included fire and tornado warning alarms. Fire and tornado warning alarms fall into the category of one way signals. One way signals

are intended to be received only.[123] The opposite of a one way signal is a two way signal. Two way signals are designed so that information be transmitted as well as received.[124] A simple example would be a hand held radio that can transmit and receive information. This section will provide examples of the many one way signals used by emergency management to communicate with the public during disasters. The section will highlight the Emergency Alert System and the systems recent upgrade that integrates the Emergency Alert System into the Integrated Public Alert and Warning System. The section will conclude with a description of two way systems and an explanation of why a two-way communications system is advantageous to ant colonies.

The government uses many one-way signals to communicate with the public before, during, and following emergencies.[125] Perhaps the most dense and resilient one way signal currently at the disposal of emergency managers is the Emergency Alert System (EAS).[126] The system's purpose is to give the President of the United States a means to address the public in the event of a national emergency. The system integrates TV and radio broadcasters, cable television systems, wireless cable systems, satellite digital audio radio service providers, direct broadcast satellite service providers, and wireline video service providers.[127] There are additional provisions that allow state and local authorities to disseminate information through the EAS about local emergencies and weather warnings.[128] EAS has recently become integrated into a larger alert system called the Integrated Public Alert and Warning System (IPAWS).[129] The components of the IPAWS are the Common Alerting Protocol, Primary Entry Point Stations, Integrated Public Alert and Warning System Open Platform for Emergency Networks, EAS, and

123 Bruce R. Lindsay, *Social Media and Disasters Current Uses, Future Options, and Policy Considerations* (Washington, DC: Congressional Research Service, 2011), 4.

124 Ibid.

125 Ibid.

126 Emergency Alert System, Federal Emergency Management Agency. Last modified July 24, 2014. https://www.fema.gov/emergency-alert-system.

127 Emergency Alert System, Federal Communications Commission. Last modified January 5, 2015. http://www.fcc.gov/guides/emergency-alert-system-eas.

128 Ibid.

129 Integrated Public Alert and Warning System, Federal Emergency Management Agency. Last modified February 26, 2015. https://www.fema.gov/integrated-public-alert-warning-system.

Wireless Emergency Alerts.[130] IPAWS is an updated version of EAS that creates new capabilities for emergency management. The new capabilities include the ability notify the public through wireless devices, such as cell phones, and a new communications platform that is to be used between emergency service providers.

Currently, there is no two-way communications system that is officially used by the government to communicate with the public during emergencies. However, obtaining information from the public can be useful to emergency management. The information can help determine the locations of victims, assess the needs of affected communities, and monitor the changing conditions of the event.[131] Emergency management can use the information to direct resources in order to reduce damages, loss of life, or both. If used properly, it is possible to obtain this information before first responders.[132]

An advantage to using a two-way communications system is that it allows information to be pulled from the public. Ants use a two-way communications system and the design of the system makes the information more accurate than the one way amplification system used by humans. As explained in Chapter II and III, ants contribute to signals as individual ants agree with the signal. The signal becomes more accurate as the signal grows in strength, because a strong signal is indicative of many ants agreeing with the condition. The colony makes semiochemical deposits in the environment which are simply information. When viewed from above, the territory that an ant colony exists in would look like a map on which the information changes as the environment changes. The map is accurate because the many individuals of the system constantly contribute to the information and ensure that that map remains up to date.

B. SOCIAL MEDIA

The value of a two-way communications system is not lost on humans. Emergency management organizations have been increasingly turning to social media as

[130] Wireless Emergency Alerts, Federal Emergency Management Agency. Last modified August 04, 2014. https://www.fema.gov/wireless-emergency-alerts.

[131] Lindsay, *Social Media and Disasters Current Uses*, 4.

[132] Ibid., 6.

a means establishing a two-way communications system with the public for use during disasters and emergencies. Bruce Lindsay defines social media in a Congressional Research Report as any, “Internet-based applications that enable people to communicate and share information.”[133] A few examples of social media platforms include Facebook, Twitter, and Instagram. Many of the attempts to use social media for gathering information have had success. This section will review the social media experience of the Los Angeles Fire Department (LAFD) and emergency management following the 2010 earthquake in Haiti.

LAFD was one of the first large-city fire departments to adopt the use of social media by starting an active Twitter engagement program.[134] Twitter is an Internet application that allows users to send short messages to followers.[135] In the early stages of using social media, the Los Angeles Fire Department was able to use Twitter to provide first aid advice and identify the locations of emergencies, such as grass fires. However, the Fire Department was reluctant to use social media as a replacement to the 911 call center due to fears that the information would be inaccurate.[136] An additional concern was the lack of personnel. In 2010, LAFD only had three people dedicated to engaging the public through social media. The firefighters monitoring social media were quickly overwhelmed by the large quantities of information attained through social media.[137] Due to institutional and political resistance, the LAFD was also having difficulty with attaining the financial support required to expand the new program.[138]

Emergency managers attempted to gather information through social media following the 2010 earthquake in Haiti.[139] Emergency management’s goal was to create

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[133] Lindsay, *Social Media and Disasters Current Uses*, 6.

[134] Mark Latonero and Irina Shklovski, “Respectfully Yours in Safety and Service: Emergency Management & Social Media,” *Emergency Management and Social Media Evangelism* 7 (2010): 5.

[135] Ibid., 2.

[136] Ibid., 6–7.

[137] Ibid., 7–9.

[138] Ibid., 8.

[139] Nathan Morrow et al., “Independent Evaluation of Ushahidi Haiti Project,” Ushahidi Haiti Project, April 08, 2011, 2. http://www.ushahidi.com/2011/04/19/ushahidi-haiti-project-evaluation-final-report/.

a crisis map of the affected area from information gathered through email, social media, text messages, and a website.[140] The crisis map would create a product that would function the same as the accurate map created by ants when ants leave semiochemical trails. The project was called the Ushahidi Haiti Project (UHP) and was a success.[141] However, the data utilization rate was low. Emergency management received over 80,000 messages. Of the 80,000 messages only 3,584 messages were mapped.[142] A major factor contributing to the low utilization rate was that geo-locational information had to be identified in the content of the message.[143] Only 3,584 had the locational information and could be used. Additionally, emergency management is unaware of the exact number of messages that were translated. Estimates are between 60,000 and 10,000. All of the translated messages were translated by individual people.[144] Although the few thousand messages mapped provided valuable information, it is evident that using social media to gather information is cumbersome for emergency management to evaluate and the result is a low data utilization rate.

Other drawbacks to using social media for establishing a two-way communications system include: the user base of social media is not representative of society; and the ability for users to pass forward information creates difficulties with verifying the accuracy of information. The primary users of social media are not a random sampling of a geographical area.[145] Social media tends to be used more by younger demographics. Additionally, the large number of social media options limits the sample size to only the information that the government can afford to monitor.[146] If emergency management only has the resources to monitor Facebook, than information reported on Twitter will never be utilized. Specific information about the emergency may also be inaccurate. Social media allows users to share and pass forward information.

[140] Morrow et al., "Independent Evaluation of Ushahidi Haiti Project," 19.

[141] Ibid., 2.

[142] Ibid., 15.

[143] Ibid., 22.

[144] Ibid.

[145] Lindsay, *Social Media and Disasters Current Uses*, 5.

[146] Ibid., 5.

Following the 2011 earthquake in Japan, Twitter posts from victims continued to be passed forward even after the victim was rescued.[147] The cumbersome and expensive task of sorting data, the biased demographic of social media users, and the difficulty in verifying information combine to make social media an inefficient source for gathering information after a disaster. However, the successes experienced through social media proves the concept that establishing two way systems will be beneficial to emergency management.

C. POST-EVENT RAPID ASSESSMENT SURVEY

Chapter II explains how emergent organizations perform better when the organization is built upon dense and interconnected systems that has a simple design.[148] The remainder of this chapter will make an argument that IPAWS is a dense and interconnected system and can be used to facilitate a post-event rapid assessment survey following disasters. A post-event rapid assessment survey, a term created by this thesis, is a simple method of allowing the public to provide emergency management information regarding the current conditions of a citizen's immediate area. The processing of the information about conditions will result in an accurate, data-filled map with information useful to emergency management for making decisions about resource allocation. In conclusion, an argument will be made that if emergency management has more accurate information about local conditions, than emergency management will better align management goals with the goals of the first responders. Therefore, an efficient information gathering system facilitates and aids the inevitable autonomous response described in Chapter I.

IPAWS is capable of disseminating a widespread request for the public to partake in a post-event rapid assessment survey. In April 2012 the Federal Emergency Management Agency (FEMA) activated Wireless Emergency Alert (WEA) capabilities.[149] WEA allows authorized government alerting authorities to send messages

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[147] Lindsay, *Social Media and Disasters Current Uses,* 4.

[148] Steven Johnson, *Emergence: The Connected Lives of Ants*, 78.

[149] Wireless Emergency Alerts, Federal Emergency Management Agency. Last modified August 04, 2014. https://www.fema.gov/wireless-emergency-alerts.

through mobile carriers and are received by the public in the form of a short message service (SMS), which is also referred to as a text message.[150] Although, WEA is currently used as a one way communication system for conveying messages about severe weather notifications, national emergencies, and America's Missing Broadcast Emergency Response (AMBER) notifications, there is no restriction to using the same technology for post-disaster notification.[151] If a message is delivered post-event, the message can contain a link to an emergency management website that is purposed to conduct a survey. Delivering a link through WEA will reach a large segment of society. Recent estimates suggest that eighty percent of adults in the United States have a mobile phone with Internet capabilities.[152] Contacting the public through the WEA will reach a larger subsect of society than using social media.

The infrastructure to facilitate a survey is already resilient because the data can be transmitted through any wireless local area network (WLAN), also referred to as Wi-Fi, or through mobile carrier connectivity, commonly referred to as a cell tower.[153] The two infrastructures can facilitate a survey and eighty percent of adults have the ability to receive the request to partake in the survey.[154] Although the technology is dependent on electrical power, redundancy can be added to the current infrastructure through the use of balloons and aircraft. Google has an Internet infrastructure project called project loon. Under the project, Google floats WiFi providing balloons into the stratosphere to create a sustainable communications network.[155] A single balloon is able to provide Internet connectivity to an area twenty five squared miles large. Although a network placed in the stratosphere may be impractical, the balloon can instead be tied down to a single location, such as a disaster relief shelter. The balloons can double, in addition to a means of

[150] Ibid.

[151] Ibid.

[152] Ingred Lunen, "80% of All Online Adults Now Own Smartphone, Less Than 10% Use Wearable," Tech Crunch, January 12, 2015. http://techcrunch.com/2015/01/12/80-of-all-online-adults-now-own-a-smartphone-less-than-10-use-wearables/.

[153] Wireless Emergency Alerts, Federal Emergency Management Agency. Last modified August 04, 2014. https://www.fema.gov/wireless-emergency-alerts.

[154] Lunen, "80% of All Online Adults Now Own Smartphone, Less Than 10% Use Wearable."

[155] "Project Loon," Google. Accessed February 26, 2015. http://www.google.com/loon.

Internet communication, as a visual aid for the citizens who lack a smart phone.[156] The same technology can be installed onto aircraft. Only a few aircraft would be required to ensure that a post-disaster survey could be conducted anywhere in the United States within a few hours.

The use of Internet capable devices will also allow the survey to be geo-stamped and time stamped. Mobile phones and computers have the ability to geo-tag information. Geo-tag is a term that is used to describe the process of enhancing data by attaching location information to it.[157] Time stamped applies to attaching the time to the same information. In order for data to be useful and measured for relevance it needs to have location and time information incorporated with the data.[158] The attachment of location and time information will make the information that is gathered from a post-event survey more accurate than the information attained through social media.

Improving the accuracy of classification is one of recommendations that came from the UHP.[159] The Haiti project categorized the information into categories and then subcategories. The review found that the coding was negligibly useful. The coding had a high error rate in addition to the low utilization rate. The review found that 36% of messages that were map had an error associated with the information.[160] The errors included non-substantial and duplicate information. This thesis argues that using categories to code information is useful. The categories were chosen by emergency management because each category represents information that is useful to emergency management. The categories aid in making accurate assessments of the situation. The project gathered information from ad hoc messages generated by the public. When information fell into categories of usefulness, the information did so by chance and not by design.

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[156] "Project Loon," Google. Accessed February 26, 2015. http://www.google.com/loon.

[157] Lindsay, *Social Media and Disasters Current Uses*, 7.

[158] Morrow et al., "Independent Evaluation of Ushahidi Haiti Project," 24.

[159] Ibid., 31.

[160] Ibid., 24.

A survey that contains simple qualification statements will make it easier to classify information and to process large quantities in a timely manner. The survey will simplify the communications between the public and emergency management. This thesis defines simple qualification statements as questions that can be answered in multiple choice formats or numeric answers. A survey could be designed to ask an initial question that identifies applicable categories and subsequent question designed to gather useful information based on the categories that apply. An example of the first question would be, "Check the boxes for all of the conditions that apply to you or the people in your immediate area." The categories could include: injuries, fire, flooding, building damage, resource scarcity, security issues, etc. For each box checked, additional questions can be asked to gather more specific information about the conditions experienced in the immediate area. If the box for injuries is selected, the more specific questions could include, "how many people are injured in your immediate area?" or "classify the injuries as life threatening, minor, etc."

Conducting a survey in this manner guides the public to provide information in a standardized format which is quick to process. Another advantage conducting a survey in the previous format is that it allows emergency management to solicit information that the participant did not originally think to include. Creating categories keeps the communication between the public and emergency services simple just like the simple language of the ants. Chapter II explained how the simple design prevents complicated micro-motives from influencing upwards into the system as a whole.[161] A survey keeps the communication between the public and emergency management simple.

There are legitimate concerns about the government collecting data regarding information gathering for emergency management use.[162] Another advantage to using the IPAWS to request information from the public is that the process ensures that the data used by the government is submitted voluntarily by the public. The current means of gathering information from social media requires the government to actively sift through information submitted by the public to an open domain that is not likely to be intended

[161] Steven Johnson, *Emergence: The Connected Lives of Ants,* 78.

[162] Lindsay, *Social Media and Disasters Current Uses*, 5.

for government use. Although the information submitted to social media is of fair use, this thesis argues that the public has more reason to be concerned about the governments use of the information posted on social media than the information submitted through a standardized survey.[163] The information submitted to social media outlets is ad hoc in nature and can easily be interpreted to have a meaning that the author did not intend. The simple and guided information provided by means of a survey is less likely to be interpreted incorrectly.[164] If the government uses voluntary surveys as a primary source for gathering information, than the method ensures that the data is gathered consensually.

A Post-Event Rapid Assessment Survey is critical to facilitating emergence because it has the capability to quickly align the goals of emergency management with the goals of first responders. As identified in Chapter I, ICS is a system that uses a top-down approach to create a centralized coordination system for resource allocation and conflict resolution.[165] The purpose of ICS is to make decisions as to resource allocation and create a means for conflict resolution. The problem, also identified in Chapter I, is that first responders act autonomous from emergency management. The reason first responders act independently is because the responder acts in accordance with the information gathered from the local environment instead of in accordance with directions generated by off location management. This thesis argues that the more accurately information is conveyed to emergency management about the environment in which the first responder operates, the more likely the goals of emergency management will reflect the goals of the first responder.

D. CONCLUSION

This thesis began by examining the shortcomings that ICS has with supporting the inevitable autonomous response to a disaster. Chapter I identified that organizations with a large degree of autonomous actors are emergent organizations. The same organizations form from the bottom-up, by first organizing many small and local groups, and secondly

[163] Lindsay, *Social Media and Disasters Current Uses*, 5.

[164] Ibid., 8.

[165] Buck, Trainor, and Aguirre, "A Critical Evaluation of the Incident Command System and NIMS," 1.

connecting the groups into an overall network. Lastly, the chapter identified the ant colony as the perfectly emergent organization. Chapter II provides a basic understanding of how an ant colony organizes. The chapter additionally uses the ant colony to provide a better understanding of how perfectly emergent organizations work. Ant colonies are perfectly emergent organizations because ants lack the intelligence to orchestrate the activities of the colony. Instead, each ant in the colony makes an independent decision as to how to function and the function is determined by the knowledge that the ant acquires from the local area. Each ant in the colony maintains unique micro-motives and the sum of the micro-motives creates a colony macro-behavior. Emergent organizations function best when the organization is built around a dense and redundant communications system.

Chapter III compared ant colonies to human organizations with respect to the communications system and ritualization process of each. Both ants and humans use a communications system designed to connect independent actors. Consequently, the signals transmitted in each organization function as condition setting signals rather than giving orders. A difference is that ants rely on evolutionary ritualization in order to establish a communications system and humans use learning ritualization to do the same. The ant's reliance on evolutionary ritualization fails to allow structural adaptability in the ant colony. The lack of adaptability makes the strategies that the colony implements time tested and an effective benchmark for comparison to human organizations. The humans' learned ritualization allows for human organizations to be adaptable quickly when compared to organisms that use evolutionary ritualization.

Another difference is that ants rely on a communications system that grains in strength as the individual ants contribute to the signal. Humans, on the other hand, use technology to amplify the signals of one or few people. The consequences of the differing designs are that ants have positive feedback incorporated in the communications systems and the information becomes more accurate. Differently, human signal are less accurate, but the amplification removes the need for member density in order to propagate a signal.

The chapter develops the primary argument of the thesis, which is to advocate for emergency management to transmit a request, though IPAWS, for the public to conduct a

post-event rapid assessment survey. The IPAWS communications system is dense and redundant because it uses both Wi-Fi and cell phone towers to transmit information. The system can be increased in redundancy through the use of balloons and aircraft. The survey keeps the communication between the public and emergency management simple. The simplicity of information will allow for emergency management to create an information map, similar in function to the information map created by ants. The map will be used by emergency management to ascertain an accurate assessment of the conditions in the localities. The accurate assessment of conditions will allow emergency management to better align management's goals to the goals of first responders. The building of a dense and interconnected system with a simple design will allow emergency management to facilitate the inevitable autonomous response.[166]

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[166] Steven Johnson, *Emergence: The Connected Lives of Ants,* 78.

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